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GRAPHICAL DETERMINATION: ALTITUDE AND AZIMUTH OF THE SUN

By CLARENCE H. TRUE

A SIMPLE graphical method of determining in advance the altitude and azimuth of the sun in any part of the world for any given time has been developed recently. Astronomers, engineers, city planners and navigators can use this graphic method to advantage. Altitude may be described as the angular distance in degrees that the sun or observed body is above the horizon, measured from the observer's position. Azimuth may be described as the direction, or the true bearing of the sun, or star, from the observer's position, and is measured in degrees.

The Earth Chart shown, Figure 1, is an orthographic projection of the earth. In other words, the chart is a projection of the earth's surface normal to the polar axis. There is no distortion of the parallels of latitude, or meridians of longitude. Therefore the parallels of latitude are straight lines, and the longitude distances between the meridians decrease as we approach the boundary or rim of the earth sphere. The chart is not to be viewed as a flat surface, but a sphere representing the earth. The meridians on the charts shown are spaced 10° apart. Three points, *A*, *B*, and *C*, are located on the chart. Points *A* and *B* are on the outer rim, and the meridians through *A* and *B* are 180° apart; or one-half the circumference of the earth. The meridian through *A* is west of *B*. The longitude distance or departure from *A* to *C* is 110° East. The departure from *B* to *C* is 70° West.

Time and Distance

The circumference of the earth at the equator equals $360° \times 60 = 21{,}600$ minutes of arc, or 21,600 nautical miles. As it takes the earth 24 hours to rotate once on its axis, it can be said that

24h = 360° = 21,600 nautical miles
1h = 15° = 900 nautical miles
4m = 1° = 60 nautical miles

As we approach the poles, the longitude distance between the meridians decreases. The variation is from 60 nautical miles per degree at the equator to 0 nautical miles at the poles.

At noon the sun is approximately on our meridian, and at 2 P.M. is about 2 hours or 30° west of us. At 7 A.M. the sun is about 5 hours or 75° east of us. Actually there are two factors which effect the problem. One is the equation of time, which varies from zero to 16 minutes; and the other is that unless we are located on a standard time meridian, an additional correction must be made. However these two factors will be ignored in this description, as it is desired to present the general procedure, without confusing the reader with details that can be learned later.

Declination North + South −			
Jan. 1	− 23°	July 1	+23°
15	−21°	15	+21½°
Feb. 1	−17°	Aug. 1	+18°
15	−13°	15	+14°
Mar. 1	−7½°	Sept. 1	+18°
15	−2°	15	+3°
Apr. 1	+4½°	Oct. 1	−3°
15	+10°	15	−8½°
May 1	+15°	Nov. 1	−14½°
15	+19°	15	−18½°
June 1	+22°	Dec. 1	−22°
15	+23°	15	−23°

The declination of the sun should be understood, and is given for various dates in the adjoining column. Declination can be compared to latitude, and is the latitude of the sun's subsolar point. A person located at the sun's subsolar point would see the sun directly overhead. For instance, if a person at latitude 20° North observes the sun directly overhead, then the declination of the sun would be +20° or 20° North, the same as the observer's latitude.

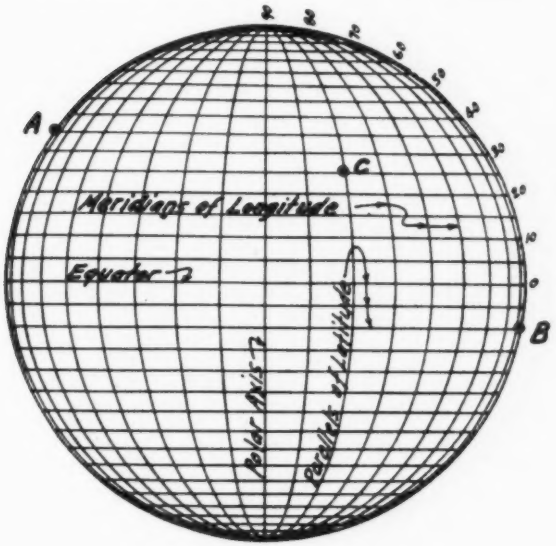
A
C
Meridians of Longitude
Equator
B
Polar Axis
Parallel of Latitude

FIG. 1

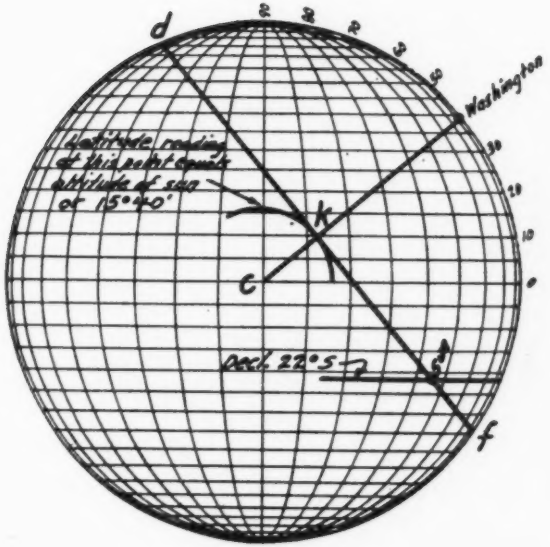
d
Washington
Latitude reading at this point equals altitude of sun at 15°40'
K
C
Decl. 22°.5
f

FIG. 2

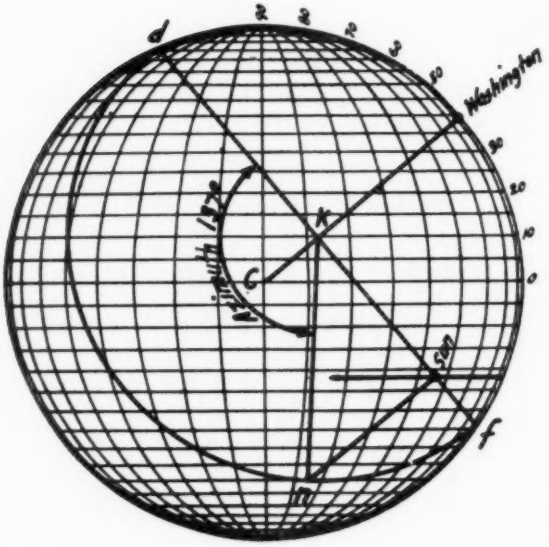

FIG. 3

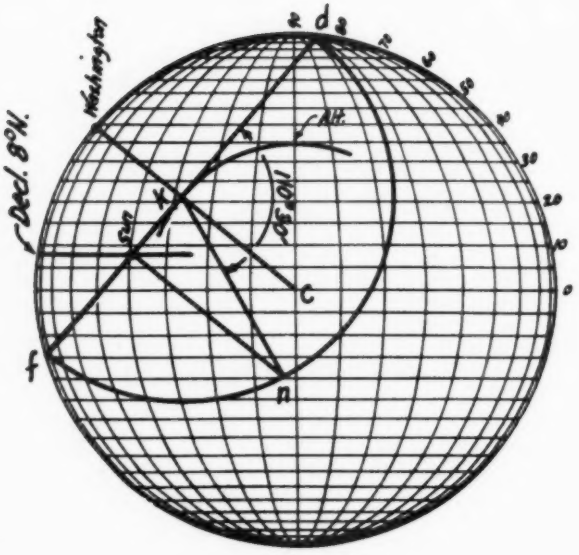

FIG. 4

PROBLEM 1.

Find the altitude of the sun at Washington, D.C., on December 2, 1944, at 3 P.M.

Latitude at Washington is 39° North and the declination of the sun December 2 is 22° South. At 3 P.M. the sun is 3 hours west of Washington, and the 3 hours or 45°, is called the Local Hour Angle.

Locate Washington on the Earth Chart (Figure 2) at Latitude 39° N. on the right-hand side, at the outer meridian. Then locate the sun 45° west of Washington at declination 22° south. Draw a straight line or radius from Washington to *c*, at the centre of the chart. Draw another line through the sun perpendicular to the first line forming a cross, intersecting at *k*. With *c* as a centre and *ck* as a radius describe an arc intersecting the polar axis. The latitude reading at this intersection is 15° 40′ and is the altitude of the sun for the given time at Washington, D.C.

To find the azimuth of the sun:—For clearness a new diagram is used. See Figure 3. With *k* as a centre and *kd* as a radius; describe the semi-circle. A line drawn from the sun perpendicular to the line *df* intersects the semi-circle at *n*. Draw *nk*. The angle *dnk* is the azimuth; and measured with a protractor is found to be 137°. The true bearing or azimuth of the sun is 137° west of North; west because the sun is west of Washington, and north because Washington is north of the equator.

PROBLEM 2.

Consider the same location, Washington, D.C., September 1, 1944, at 8.37 A.M. In this problem the sun is east of Washington 3h 23m in time, or 50° 45′ of arc. Washington will be located on the left side of chart at latitude 39° N. and the sun's subsolar point will be located east, or to the right of Washington 50° 45′; and at declination 8° North (see Figure 4). The same general procedure is now followed as in the previous problem. The altitude of the sun is found to be at 35° and the azimuth 110° 30′ east of North, or N 110° E.

By using larger Earth Charts, and by taking into account the equation of time, as well as the correct Local Hour Angle based on

the observer's true meridian (in place of the standard time meridian) accuracy to within one-quarter of a degree can be obtained.

Earth Charts of 9, 19 or 30-inch diamater are available, with the meridians spaced 2° apart.

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Box 318, Balboa Heights, Canal Zone.

A VISIT TO DUNLAP OBSERVATORY*

LET'S visit. When gasoline was plentiful and threadbare tires were not a worry and you were driving up Highway No. 11, just before you came to Richmond Hill, you noticed Dunlap Observatory and said to yourself, "One of these days when I am not in such a hurry, I am going to stop off and see that place." But unfortunately Dunlap Observatory has been closed to visitors for the duration of the war. However, we did call and Professor R. K. Young, who was in charge of this observatory, made a rare exception to this rule and kindly consented to show us around.

Conversation in the Director's Office

Professor Young, could you tell me to whom you are indebted for this observatory and something of its origin?

The observatory is the gift of Mrs. Jessie Dunlap to the University of Toronto as a memorial to her husband, David A. Dunlap. Acquisition of the observatory is to no small extent due to the efforts of Professor Chant of the University of Toronto. For years Professor Chant had been urging the advisability of the University obtaining an observatory and he never failed, at his public lectures, to emphasize the need of such an observatory. Among the listeners to his lectures at the Royal Astronomical Society was Mr. Dunlap, who was himself an amateur astronomer and interested in astronomy. It had been Dr. Chant's idea that possibly Mr. Dunlap would provide the funds for such an observatory, but he prematurely passed away. A year or so later, Professor Chant approached Mrs. Dunlap and suggested that possibly she might provide funds for an observatory as a memorial to her husband and his proposal met with a very ready response and she agreed to provide funds for the observatory. This was in 1928.

Now, do you find that the war has interfered with the work at the observatory, Professor?

Yes, to quite a considerable extent. We have lost the services of a number of our young men to the war effort. There was Lieut. G. H. Tidy, who was in the Navy and was lost on the *Exeter* in the

*This was a broadcast over station CJBC of the C.B.C. in the series "Let's Visit."—*Editor.*

battle of Java. Fortunately, he was rescued and is now a prisoner-of-war. We lost the services of Dr. P. M. Milman and Dr. J. F. Heard, who for years have been teaching aerial navigation to the Air Force. We lost the services of Mr. G. F. Longworth, who was our machinist and night observer; but apart from these, we have tried to carry on the work of the observatory on the same lines as we did before the war started and while we have had to curtail the building of new apparatus, still we have managed to use the telescope and obtain observations from sunset to sunrise on every clear night. We have been a little behind possibly in keeping up with the observations and we have not been able to obtain new apparatus and keep the library in as good shape as we would like to see it. Otherwise things have gone on the same.

Just what is the work, that is, the nature of the work that is carried on at an observatory?

Well, there are many observatories situated throughout the world and they do not all work on the same programmes. Of course, observatories wish to find out the nature of the stars, what their past history has been, where we are situated among them and what their future is going to be. When you look at a star through a telescope, it is a point of light, just as it is a point of light to the naked eye. No magnification is sufficient to make the stars anything but points of light.

All our knowledge that we get from the stars must come down in that little bit of light that they send to us. They are too far away for us to see any detail of their surfaces. Now, we can measure the the position of the stars; we can measure the amount of light that they send to us; we can measure the quality of the light they send down; and the various observatories throughout the world are working at problems related to these various quantities.

We at this observatory are working upon the quality of the light that the stars send to us. Now the quality of light is analyzed by an instrument that they call the spectroscope and we get photographs of that light in the spectroscope and from those photographic pictures we can tell how fast the stars are moving to or from us; we can tell what the constitution of those stars is and their temperatures and we can tell how far the stars are away. Since the observatory opened in 1935, we have obtained some 11,000 of these

pictures of the stars and determined the speeds at which approximately 1,600 of them are moving. We are at present engaged on a programme which will enable us to determine the distances of most of these stars.

Well now, Professor, may I ask just what value is the astronomical knowledge that is gained at an observatory?

Well, when we speak of the value of a subject, we think of its, say, cultural value or its value in dollars and cents. To go away back when the subject first started, there was a time when every person considered that the world was flat, that underneath it possibly was a region of fire, that the stars even were living beings and pursued their paths across the heavens at their own will, and that they had a direct influence on the affairs of the world. It was impossible at that time, when the people thought it necessary to propitiate the beings that controlled the world about them by sacrifices, for any progress to be made in the true sense of the word. It was not possible for us to get a true idea of our place in the universe until Copernicus conceived the idea and presented evidence that the sun was at the centre of our system and that the earth was a ball and was going round the sun and was turning on its axis. In fact, at that time science awoke and the world started to study things. Later, and coming to modern times, there is a value in dollars and cents. Astronomy is one of the sciences and the workers in the various sciences have sometimes to appeal to all the sciences for solutions of the problems on which they are working. The knowledge that is found in any one science is of value to workers in another science. Possibly, there is no science which has contributed more in dollars and cents to the world, than the science of physics and one of the outstanding problems that they have been working on in physics is the structure and nature of the atom. Astronomy has contributed a great deal to our advancement in the knowledge of the atom and in this way, the physicist in his laboratory knows what is going to happen to matter and to the atom when it is subject to temperatures of, say, 4000 degrees in the electric arc. But in the sky we have stars where the temperatures rise to 6000, 7000, 10,000 or even 30,000 degrees Centigrade, and in that way it supplements to a very large extent the physics laboratory in telling what is going to happen to the various elements when they

are heated to these very high temperatures. Of course, in dollars and cents, astronomy looks after the calendar; it looks after the time and after the survey of the earth's surface in the various countries.

Thank you very much, Professor Young. I might explain to our listeners that this interesting discussion took place in Dr. Young's office and I am most anxious to get over and see that telescope, Professor. Do you think that would be possible?

Yes, we'll go over.

Description of the Telescope

As we approached the building that houses the telescope, we noticed that it was of a circular design with a hemispherical dome resting on top. But now we are inside, perhaps Prof. Young you would be good enough to explain the lower floor to our listeners.

This floor houses the electric equipment that controls the telescope in the upper story and upon the large cement piers that you see here the telescope rests. The piers go down in the earth about 25 feet and are free in every way from the building so as not to take up any shaking by wind that the building might experience or any tremors that might come from passing trains and so on. But let us go upstairs. We will just walk along this way and up the circular metal stairs that lead to the second floor, that is, to the dome proper where the telescope actually is.

And as we approach we get a view of the telescope and I can honestly say that I am almost speechless with the immense size of this telescope. I had no idea of it. I have seen a few of the telescopes, that I am sure are common to our listeners as well, but I have never seen anything of such magnitude. Possibly, Professor, the best question I can ask you right now is, How much does it weigh?

Well, the moving parts of the telescope weigh about 50 tons.

About 50 tons!

Possibly the best thing I can do is to give you a short description of the telescope and the way it operates.

The main part of the telescope, the part that you usually think of, the big mirror, is a disc of glass about 74 inches in diameter, about 12 inches thick and it is ground slightly concave on its front surface

and silvered. The mirror is about one inch thinner at the centre than at the edge. The light from a star or any object toward which the telescope is directed, comes down through the opening in the dome and falls in parallel rays on this concave surface and is converged back towards the upper end of the telescope. Before coming to a focus it falls on a mirror which returns it to the base end and the light passes through an opening in the large mirror and comes to a focus about 12 inches below the main mirror. An eyepiece can be placed there and any object viewed or a photographic plate or other instrument can be placed there and the object photographed. We use the telescope almost entirely photographically and take pictures of the stars from sunset to sunrise. These are the optical parts of the telescope, the big mirror at the base and the smaller mirror at the top. The big mirror at the base weighs about 2½ tons. The small mirror at the top is of very minor weight and you might wonder why such a massive mounting has to be constructed to carry these two parts. Well, possibly you can understand something of the reasons why the main mounting has to be so massive when I tell you that when you direct this telescope toward an object in the sky, such as a star, the field of view is very small. It is like training a cannon on a target, say a penny, at a distance of 15 miles, and the penny moving with a velocity across the line of sight, say, at 5 or 6 feet a second, and you must point the optical parts of the telescope or the cannon, to use that metaphor, so that the cannon would be pointed at that penny and continue to point at it as the penny moved across the line of sight. Now, to do that accurately and smoothly, it is necessary that the telescope move with the greatest precision and also that we be able to point it with ease. That can only be accomplished by having a correspondingly heavy mounting. Of course you know that objects in the sky rise in the east, come across the sky and set in the west, just as our sun and moon seem to do from day to day and night to night. In consequence of that motion, any object, when you once get it in the field of view of the telescope, would move out very quickly and, due to the magnification in the telescope, move out almost instantaneously, if it were not that the telescope was moved in such a way as to apparently counteract the rotation of the earth. In order to effect that, the telescope is mounted in this peculiar manner.

The mounting consists first of the large tube that houses the two mirrors. The lower part of this tube is a steel casting and the upper part an open framework. That open framework is designed so as to let the air circulate freely through the tube, because it has been found that any stagnant air that is liable to accumulate in a closed tube can very materially affect the definition of the telescope. The tube is mounted on a steel arbour, about 14 inches in diameter and 25 feet long, which runs at right angles to the tube and it turns on a bearing so that the telescope can be turned and elevated at different elevations above the horizon, setting the telescope in a position which corresponds, as it were, to different latitudes on the surafce of the earth. That axis in turn is mounted on another axis which we call the polar axis and which is parallel to the earth's axis. The telescope, when it is turning by clockwork, turns continuously about this axis, parallel to the earth's axis, making one revolution in 24 hours. The lower part of this axis has a big circle graduated upon it and we can read on that circle the positions of the stars corresponding to longitude on the surface of the earth. All the stars in the sky, that is thousands and hundreds of thousands, have their positions recorded in catalogues according to these two positions, latitue dand longitude. Actually, we call them right declinations and right ascensions but they are similar to latitude and longitude, and when you have set a telescope to the proper position in latitude and the proper position in longitude for any star, and opened the dome and turned the dome to the correct position so that the telescope can see out (I haven't explained that yet) then when you look through the telescope, you should be able to see that star there. Now I might explain that, in order to have the telescope able to see any part of the sky, the dome, which is hemispherical, revolves on 24 rollers on tracks so that it can be turned in any position in the sky and then a section of the dome is opened by two shutters, so that a slit is provided from the bottom of the dome to the top; and this, in conjunction with the dome being able to be turned, enables that opening to be brought in front of the telescope no matter in what position the telescope happens to be.

I am only sorry, Professor, that it is daylight, and much too light to see a star, because I would certainly like to be able to see one.

Well, it is quite possible to see almost any of the stars that you

can see with the naked eye at night, for they can be seen with the telescope in the daytime. Maybe you would like me to show you one.

I would very much, if you would be kind enough to do that. I know that it means going through all the operations that you usually perform in order to see a star, bit if you would not mind, I certainly would deem it a pleasure if you would show it to me.

If you will just bear with me a moment, I will open the dome and get things going.

And just before you leave, How much does the dome weigh, Professor?

The dome weighs about 80 tons, that is the turning part of the dome.

All right, sir, fine. Now Professor Young is just going around to the motors here, passing to the telescope and possibly you can hear him turn the switch that turns the generator on down on the floor below that will in turn give the power to turn this huge dome that weighs something over 80 tons. Really, to see this telescope, it was my fondest dream. Professor Young is now opening the slit in the ceiling of this dome. Perhaps you can hear it being opened. It opens up, I imagine, to a distance of about 15 to 20 feet and covers half the opening of the dome which will permit the telescope, as Professor Young explained, to peer out through at the stars. Professor Young is returning now down from the balustrade which goes around the dome and will continue his discussion from here.

Well, we will now turn the dome so it will be in the correct position and the telescope be able to look out when it has been oriented in its proper place.

All right. And whether you can hear that or not, this whole dome is moving at the touch of a button by Professor Young. The dome is being moved around to the south and possibly you will be able to hear the whistle of a train when Professor Young speaks. All that would have a tendency to vibrate the building if it were not constructed in this particular way. But we are trying to aim on what particular star, Professor?

The star we are aiming to set on is the bright star Arcturus, that has a position in the sky of declination 19 degrees and 26 minutes, and 14 hours and 11 and a fraction minutes in right

ascension. We will now set the telescope in right ascension. That is the clamp of the telescope coming off.

Yes. And Professor Young is just about to move the telescope around, which he does with a small wheeel attached to the side and when something like over 50 tons can be moved with the touch of a finger, really once it is set in motion with this wheel, it is about comparable to the size of the driving wheel of an automobile, that is now being swung around so that the point of the telescope is looking out through the opening of the dome. There is certainly a great deal to the adjustment of this telescope. The dome is now being moved back a little bit so that we will be able to see out through this opening in it, which was created when the doors were moved back, and as we look out we see an aeroplane passing along.

Now, if no mistakes have been made, a star should be found in the field of the telescope. I am just going to move this chair over and we will take a look through the eyepiece.

Well, thank you very much. Is it all right, Professor, if I go up and see it?

All right.

Thank you very much.

We will just climb up the side of the telescope to where this eyepiece is and see if the calculations as arranged by the Professor were correct and if we can see this star. We just approach this eyepiece, which is directly below the huge telescope, and we look through a smaller telescope called a finder, like the range-finder on a gun possibly. At the moment we can't quite see the star but then it comes into view and it is like a very tiny point of light. There are two little cross-bars like the eye sight of a gun inside of this and we can see the star just to the top and to the left of the left cross-bar. Well, certainly that is very interesting to be able to see a star during the daylight. Is it possible, Professor, at night to see more stars with the huge telescope than we see with the naked eye?

The telescope multiplies very greatly the number of stars that can be seen. With the naked eye, on a good clear night, you could possibly see 2,000 stars in the sky. Through the big telescope, one should be able to see, although you wouldn't count them, as many as a hundred million stars. Now the telescope is set on this star and if it were night-time, what we would be doing would be photo-

graphing the spectrum of this star. We work, as I think I said before, from sunset to sunrise getting these pictures and it is from these pictures that we are able to tell how fast the stars are moving and how far they are away and what they are made of. The pictures that we get this way, taken at night, are developed next day and used in the Administration Building, which is situated about 200 yards from the building in which we are now situated.

Would it be possible to leave the big telescope and go over and view some of those pictures?

Yes, we can go over there right away. Just throw the power off and then we can go over.

All right. Thank you very much.

We have here a picture of the same star that we were looking at in the dome in daylight—a spectrogram, as we call it, of Arcturus. The picture itself does not look to be a great deal. It consists of a streak of light, shown in the picture as a dark streak which, if you saw it in colour, would be red at one end and blue at the other and across this band, a great many lines which are scattered irregularly, some of them strong, some of them barely perceptible. Now it is from these lines that we are able to get much information about the stars. There are four things that this picture tells us. From the position of the lines, we are able to tell how fast the star is moving toward, or going away, from us. From the intensity of the lines, that is the fact that some are strong and others are faint, we are able to tell how far the stars are away; and from their mere presence we are able to tell what the constitution of the star is. That is to say, these lines have a definite identity, some belonging say to the element iron, some belonging to calcium, some belonging to hydrogen, and so on. As soon as we see any certain lines in the spectrum, then we know that particular element exists in the atmosphere of the star. That is three things. There is one more thing that the spectrum shows us and that we learn from the intensity of the band of light. In some stars it will be strong toward the red and in others it will be strong toward the violet. That is a matter of the temperature of the stars. We have those four things, the distance, the speed with which they are moving, what they are made of and their temperature, all of which can be told from the spectrum of the stars.

Well, certainly that is a very interesting study, Professor, and just one final question before we leave. We shall again refer to the telescope, if we may. How does the telescope compare at the Dunlap Observatory in size with any other telescopes throughout the world?

At the present time this telescope ranks as the third largest in the world. There is the hundred-inch at the Mount Wilson Observatory in California; the eighty-two-inch at the McDonald Observatory in Texas and there is a two-hundred-inch well toward completion. It is third now but it will be fourth when the two hundred inch is completed.

And how large is the mirror in this telescope?

This telescope is 74 inches in diameter. It was cast in the United States and ground in England.

And approximately how fine is it ground?

The front surface is ground in the form of a parabola and we think that nowhere is its surface more than a millionth of an inch or so above or below the correct figure.

Well, thank you very much, Professor Young. We are indebted to you and your astronomical knowledge for a very interesting and educational visit. You know, there are really so many more questions that I would like to ask, that I feel would be of interest to our listeners, about meteors, falling stars, Is Mars inhabited? and a hundred others, but time just won't permit. However, in the not too distant future, I would like to return and have you clear up a few of these little matters for me, if you would.

Possibly at some future time; perhaps after the war.

All right, and may that be very soon!

OCCULTATIONS: THEIR PREDICTION, OBSERVATION AND REDUCTION

By H. Boyd Brydon

(Concluded from page 384)

Reduction of the Observations (Continued)

More convenient formulae are given in the almanacs. Those in the American Ephemeris are:

$$\rho \cos \phi' = F \cos \phi \text{ and } \rho \sin \phi' = \sin \phi / G \qquad (14)$$

where ρ is the radius to mean sea level at geographic latitude ϕ and the logarithms of F and G are to be taken from an accompanying table. A correction for altitude H, in the form $H \cos \phi'$ and $H \sin \phi'$ must be applied to arrive at the true values of these quantities for use in reducing an occultation. The Nautical Almanac formulae include the correction for altitude. They are

$$\log \rho \sin \phi' = \log \sin \phi + \log S + f \times \text{altitude in feet} \qquad (15)$$

$$\log \rho \cos \phi' = \log \cos \phi + \log C + g \times \text{altitude in feet} \qquad (16)$$

where ρ is the ρ' of the computing sheet, the geocentric radius at sea level. Log S and log C are to be taken from Table VII "For computing the geocentric Coordinates of a Place," N.A. 1943, p. 551, and f and g from an auxiliary table on the same page. Since ρ is a length, $\rho \cos \phi'$ and $\rho \sin \phi'$ are also lengths. They are reduced to seconds of arc by multiplying each by the moon's parallax π', item 21, and are entered on the computing sheet as item 31, X'', and 34, Y''.

Signs. Since the sign of cos ϕ is always positive X'' is always positive. Sin ϕ and tan ϕ take the same sign as the latitude; north, positive; south, negative, whence Y'' takes the same sign as the latitude.

It will be of interest here to summarize the remaining objectives of the reduction by quoting the equations given by Innes, *loc. cit.* The numbers of the corresponding items on the computing sheet are enclosed in brackets:

"Use five-figure logarithms.

(*Item* 30) $x = 15(\alpha' - \alpha) \cos \delta$.

(*Item* 51) $y = (\delta' - \delta) - [4{\cdot}385]\, x^2 \sin \delta' \cos \delta.$

(*Item* 33) $\xi = X'' \sin (\theta - \alpha).$*

(*Item* 41) $\eta = Y'' \cos (\delta' - X'') \sin \delta' \cos (\theta - \alpha).$

(*Item* 54) $$\tan \chi = \frac{x + \xi}{y + \eta},$$

where χ is the angle of occultation.

(*Item* 65) $$\sigma' = \frac{x + \xi}{\sin \chi} = \frac{y + \eta}{\cos \chi},$$

the observed distance of star from moon's centre at time of observation.

(*Item* 60) $\tan \rho = 15\Delta\alpha \cos \delta / \Delta\delta,$

where ρ is the direction of the moon's motion.

The error in orbital longitude" (of the moon) "in the sense observed minus computed is

$$\Delta\nu = \sigma' - \sigma \,/\, \cos (\chi - \rho).$$"

Returning to the computing blank, item 26 ($\theta - \alpha'$) is the angular distance of the star from the observer's meridian at the time T of the phase of the occultation. It is obtained by converting the hour angle of the star $\theta - \alpha'$, item 25, from time into arc by multiplying it by 15. The conversion is most conveniently made by using tables converting time to arc.

Item 27. This is the logarithm of 15.

Item 30. x This is one of the co-ordinates of the moon's centre, see Fig. 15. It is the difference $\alpha' - \alpha$ between the right ascensions of the star and the moon expressed in seconds of arc.

The time angle $\alpha' - \alpha$ is reduced to angular measure by multiplying it by 15 and the resulting arc to the required fraction of its length at the equator by multiplying it by $\cos \delta$.

When the moon is on the equator, declination zero, $\cos \delta$ equals 1. As seen from the star the length of the arc is then the distance AA, Fig. 20. For any other declination δ the apparent length of the arc is BB which is equal to $AA \cos \delta$ or generally

$$x'' = 15(\alpha' - \alpha) \cos \delta. \qquad (17)$$

*The use of ζ (zeta) in the computing sheet to represent this co-ordinate is a misprint.

Taking logarithms as in the computing sheet

$$\log x'' = \log 15 + \log(\alpha' - \alpha) + \log \cos \delta,$$

Item 30 = item 27 + item 28 + item 29.

The antilog of item 30, the co-ordinate x in seconds of arc is to be entered in the column headed Numbers.

Sign. As cos δ is always positive the sign of x'' is the same as that of $\alpha' - \alpha$.

Item 33 ξ. This is the co-ordinate of the observer's position corresponding to the x co-ordinate of the moon's centre. It is the distance of the observer from the Y-axis, as seen from the star, projected on the fundamental plane and expressed in seconds of arc.

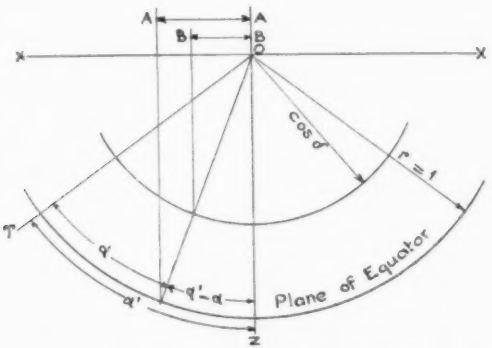

Fig. 20.—Co-ordinate x of moon's centre in terms of α', α and δ.

Since the declination δ' of the star does not enter into the computation of ξ it is convenient, in order to simplify the diagram, Fig. 21, to take δ' as equal to the geocentric latitude of the observer. In Fig. 21, the fundamental plane XY stands at right angles to the plane of the paper; O is the Y-axis seen end on and also the centre of the earth; XX' is the X-axis at right angles to OZ the Z-axis which is directed to the star.

The geocentric radius of the earth to the observer's position P being ρ', the radius R of his circle of geocentric latitude ϕ' in seconds of arc is OX equal to $\rho' \cos \phi' \sin \pi$ or X'', item 31. Let $O\Upsilon$ be the direction of the vernal equinox. Then the arc GP or angle ΥOP is

the observer's sidereal time θ; the arc GZ or angle ΥOZ is the right ascension α' of the star and the arc ZP is their difference, $\theta - \alpha'$.

Draw SP parallel to the X-axis and PQ parallel to the Z-axis. Then OQ is equal to SP which is equal to $R \sin (\theta - \alpha')$ or $X'' \sin (\theta - \alpha')$. Whence OQ is the projected distance ξ on the fundamental plane of the observer P from the Y-axis, whence

$$\xi'' = X'' \sin (\theta - \alpha'), \qquad (18)$$

or, taking logarithms: $\log \xi'' = \log X'' + \log \sin (\theta - \alpha')$.

or item 33 = item 31 + item 32.

Sign. Since X'' is positive and $\sin (\theta - \alpha')$ has the same sign as $\theta - \alpha'$, ξ has the same sign as $\theta - \alpha'$.

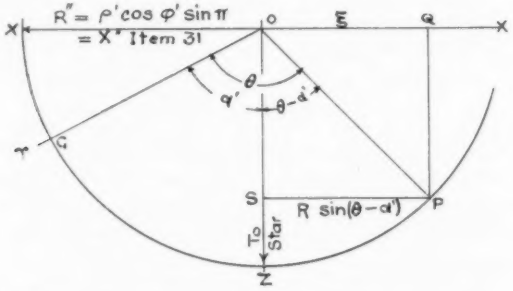

Fig. 21.—The co-ordinate ξ of the observer in terms of his radius of geocentric latitude and the star's hour angle.

Item 41, η. The co-ordinate η is the distance of the observer from the X-axis as seen from the star projected on the fundamental plane. It corresponds to the y co-ordinate of the moon's centre. It is expressed in seconds of arc and is computed by the relation

$$\eta'' = Y'' \cos \delta' - X'' \sin \delta' \cos (\theta - \alpha') \qquad (18)$$

item 41 = item 36 − item 40

Signs. Y'' takes the sign of the latitude ϕ' of the observer; $\sin \delta'$ that of the declination δ' of the star; positive if north, negative if south. $\cos \delta'$, X'' and $\cos (\theta - \alpha')$ are positive. Hence the first item, $Y'' \cos \delta'$, is positive or negative as Y'' and $\cos \delta'$ have like or unlike signs. The second term, to be subtracted from the first,

takes the sign of δ'. The sign of η thus depends on the signs and values of the three factors composing these terms: the geocentric latitude ϕ' of the observer, and the declination δ' and hour angle $\theta - \alpha'$ of the star. We consider these factors separately.

First: Let the star be on the equator, declination zero and on the observer's meridian, hour angle zero. Then referring to Fig. 19, the Z-axis, the line of sight from the star, will coincide with the line EO; the Y-axis with NS and the point O will represent the X-axis seen end on looking eastward.

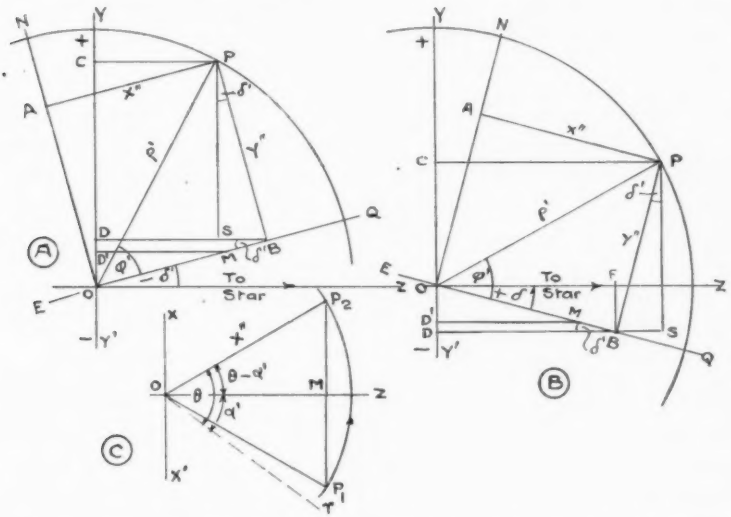

Fig. 22.—The co-ordinate η of the observer in terms of $\theta - \alpha''$, X'', Y'' and δ'.

In this case $\cos \delta'$ is 1, $\sin \delta'$ is zero and $\cos (\theta - \alpha')$ is 1. The second term of the equation disappears and we have

$$\eta'' = CO = Y''.$$

Next: Let the declination of the star be δ' and the hour angle remain zero. Since δ' may be positive or negative two cases must be considered. In Fig. 22A, δ' is negative and in Fig. 22B, positive. In both figures OZ is the Z-axis, YY' the Y-axis and the trace of

the fundamental plane which stands at right angles to the plane of the paper. The star is on the observer's meridian which is in the YZ-plane.

Let N be the (north) pole, NO the earth's axis, EQ the equator and P the observer at the (positive) geocentric latitude ϕ', and ρ' the geocentric radius to the observer's position. In both figures draw PA parallel to EQ and PB parallel to NO. Then

$$PA = \rho' \cos \phi' \pi = X'' \qquad \text{item 31}$$
$$PB = \rho' \sin \phi' \pi = Y'' \qquad \text{item 34}$$

Draw PC and BD parallel to OZ. Then angles BPS, DBO, QOZ and APC all equal the declination δ' of the star, DO equal to BF is $\sin \delta'$ and CO is the projected distance of the observer from the X-axis and is equal to η.

When δ' is negative as in Fig. 22A, DO is positive and CO is equal to CD plus DO. When δ' is positive, Fig. 22B, DO is negative and CO is equal to CD minus DO. But CD is equal to PS which is equal to $Y'' \cos \delta'$ and DO or BF is equal to $OB \sin \delta'$ or $X'' \sin \delta'$. Thus for the case when $(\theta - \alpha')$ is zero,

$$\eta'' = Y'' \cos \delta' \pm X'' \sin \delta'.$$

Third: As the effect of the declination of the star was shown by setting the hour angle $\theta - \alpha'$ equal to zero, so the effect of the hour angle is best seen by setting the declination equal to zero.

In Fig. 22C let P_1ZP_2 be an arc of the observer's circle of geocentric latitude with radius OP equal to X''. Let XX' be the trace of the XY-plane, OZ the trace of the YZ-plane and $O\Upsilon$ the direction of the vernal equinox. Then α' is the right ascension of the star, θ the observer's sidereal time and $\theta - \alpha'$ the hour angle of the star. As the rotation of the earth carries the observer from P_1 to P_2 the angle $\theta - \alpha'$ diminishes until the point Z is reached, then increases. Draw PM parallel to XX'. Then in all three diagrams:

$$OM = OB \cos (\theta - \alpha') = X'' \cos (\theta - \alpha').$$

In Figs. 22A and B draw MD' parallel to OZ. Then since triangles OBD and OMD' are similar

$$OD'/OD = OM/OB.$$

But OM is equal to $X'' \cos (\theta - \alpha')$ and

$$OD = X'' \sin \delta' \cos (\theta - \alpha'),$$

whence $\eta = CO - (\pm OD')$ as OD' is positive or negative
or $\eta = Y'' \cos \delta' - X'' \sin \delta' \cos (\theta - \alpha')$.

Item 51, *y*. This co-ordinate on the fundamental plane is the projected distance of the theoretical position of the moon's centre from the X-axis. It is positive when measured northward from the axis.

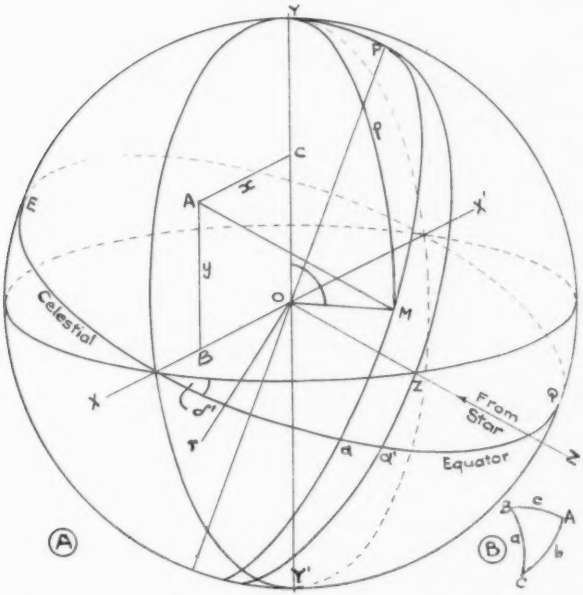

Fig. 23.—The co-ordinates of the moon's centre in terms of $\alpha - \alpha'$, δ, δ'. (After L. S. Barnes).

Let Fig. 23A represent part of the celestial sphere and O its centre, where the three reference planes of Fig. 2B intersect at right angles. The intersections of these planes mark the axes XX', YY' and OZ. The line XX' is also the trace on the fundamental plane of the plane of the celestial equator, $OE\alpha'Q$ which intersects the XZ plane at an angle $ZX\alpha'$ equal to the declination δ' of the star.

Let M be the position of the moon's centre on the celestial sphere; P the (north) pole of the sphere, OP the axis and $O\Upsilon$ the direction of the vernal equinox. Then $PM\alpha$ is an arc of the hour

circle of the moon, $PZ\alpha'$ an arc of the hour circle of the star and YM an arc of a great circle through Y and M. The arc $\alpha'Z$ is equal to the declination δ' of the star, the arc αM to the declination δ of the moon, and the arc $\alpha' - \alpha$ or the angle $\alpha'P\alpha$ to the difference between their right ascensions.

Since the plane of the equator is at right angles to OP and the YZ plane to OY, the arc PY is equal to the arc $\alpha'Z$. Draw MA parallel to ZO meeting the fundamental plane in the point A. Draw AB parallel to the Y-axis and AC parallel to the X-axis. Then A is the projected position of the moon's centre, AC is the X-co-ordinate and AB the Y-co-ordinate of the point A.

Join MO. Then MO, the centre to centre distance between the earth and the moon, is a radius R of the sphere but seen much foreshortened in the figure where OY represents its true length.

Angle YOZ being a right angle, angle YOM, or the arc YM, is equal to $90° - \delta$ and

$$CO = R \cos (90° - \delta) = R \cos p,$$

where p is the arc YM, a side of the spherical triangle PYM. In such a triangle ABC, Fig. 23B, the value of the side a can be computed by the general formula

$\cos a = R (\cos b \cos c + \sin b \operatorname{sinc} c \cos A)$, where R is the radius of the sphere.

Adapting this formula to a solution for the side $p = y$ in Fig. 23A we have:

$$\begin{aligned}
\cos\ a &= \cos\ YM &&= \cos p,\\
\cos\ b &= \cos\ PM &&= \cos (90 - \delta) = \sin \delta,\\
\cos\ c &= \cos\ PY &&= \cos \delta',\\
\sin\ b &= \sin\ PM &&= \sin (90 - \delta) = \cos \delta,\\
\sin\ c &= \sin\ PY &&= \sin \delta',\\
\cos A &= \cos MPY &&= \cos [180° - (\alpha' - \alpha)] = -\cos (\alpha' - \alpha).
\end{aligned}$$

Then $$\cos p = R [\sin \delta \cos \delta' - \cos \delta \sin \delta' \cos (\alpha' - \alpha)] \qquad (21)$$

To convert y into seconds of arc R must be expressed in terms of the moon's parallax in seconds of arc. From Fig. 16 and equation (8) we have

$$r/R = \sin \pi, \text{ whence } R = 1/\sin \pi,$$

r being the equatorial radius of the earth taken as unity. Substituting this value for R in equation (21)

$$y'' = \frac{\sin \delta \cos \delta' - \cos \delta \sin \delta' \cos (\alpha' - \alpha)}{\sin \pi} \qquad (22)$$

This is the form in which equation (21) is usually presented. However, by setting R equal to unity and making use of the auxiliary relations

$$\sin^2\theta + \cos^2\theta = 1,$$

and

$$\cos\theta = \cos^2\theta/2 - \sin^2\theta/2,$$

where θ is any angle, equation (22) can be written:

$$y = (\delta' - \delta) - 2 \sin \delta' \cos \delta \sin (\alpha' - \alpha)/2 \qquad (23)$$

(The treatment here is that in the paper by L. S. Barnes cited above)

The sine of a small angle being equal without appreciable error to the angle in seconds of arc and reducing y to seconds of arc by multiplying by sin 1″, equation (23) becomes

$$y'' = (\delta' - \delta)'' - \frac{\sin \delta' \cos \delta \sin 1''}{2} \cdot (\alpha' - \alpha)^2 \qquad (24)$$

and since by equation (16)

$$(\alpha' - \alpha) = x/\cos \delta,$$

equation (24) may be written

$$y'' = (\delta' - \delta) - \frac{x^2 \sin \delta'}{\cos \delta} \cdot \frac{\sin 1''}{2}, \qquad (25)$$

the form in which it is used in the computing sheet. Sin 1″/2 is a constant equal to 0·0002424 of which the logarithm, 4·385, (− 10 being understood) appears as item 45.

For an occultation to occur, the value of y, as shown by equation (25) must be less than $\delta' - \delta$, the difference between the declinations of star and moon and must involve a difference between their right ascensions. For first: if $\delta' - \delta$ be equal to the moon's radius, the limb of the passing moon can but graze the star and an appulse only is possible. Second: when $\delta' - \delta$ is less than the radius of the moon the right ascension of the occulting point on the limb must be greater than that of the centre in the case of a disappearance and less in the case of a reappearance.

Sign. The sign of x^2, cos δ and sin 1″/2 being positive the sign of y depends upon the signs of $\delta' - \delta$ and sin δ which will be positive or negative as conditions demand.

We now have the data needed to compute σ', item 65, and $\sigma' - \sigma$, item 67. If this difference exceeds three seconds of arc an error exists in the observational data, in the reduction, or in both. Until the error is found and corrected it is useless to compute the

intermediate items which are auxiliary to the later discussion and are not needed in the reduction. With the aid of these auxiliary quantities and analysis and discussion of a number of reductions any correction to the orbital position of the moon is determined by means of equations of the form

$$\Delta L \cos(\rho - \chi) + \Delta B \sin(\rho - \chi) = \sigma' - \sigma \qquad (26)$$

where ΔL and ΔB are the departures of the moon from the theoretical position in longitude and latitude; ρ, item 60, is the direction angle of the moon's motion and χ the position angle of the star on the moon's limb. Both angles are measured eastward from the north point of the disc and are determined by their tangents.

In addition to the auxiliary items on the computing sheet are the following, to be entered by the computer in the space indicated.

54a	Coefficiet $\Delta\delta = \cos\chi$
55	Repetition of constant 1·176
A	Log cos δ' (item 35)
B	Log sin χ
C	Sum of 55, *A*, *B*
59a	Antilog of *C*, Coefficient $\Delta\alpha$
61a	$p = \cos(\rho - \chi)$
61b	$q = \sin(\rho - \chi)$

As for item no. 45, three-figure logarithms serve for these items. The relationships between them are indicated in Fig. 24 drawn for the condition that $\sigma' - \sigma = 0$.*

Item 54. Tan χ. In accord with the form of the fundamental equation given by Innes

$$\tan\chi = \frac{x + \xi}{y + \eta} = \frac{\sin\chi}{\cos\chi}. \qquad (27)$$

Taking logs

$$\log\tan\chi = \log(x + \xi) - \log(y + \eta)$$
$$\text{item } 54 = \text{item } 52 - \text{item } 53.$$

As indicated in Fig. 24, the position of the star may lie in any of the four quadrants, depending upon the phase observed. The signs of the tangent, item 54; cosine, item 54a, and sine item B, of the position angle will change accordingly as shown below.

*A diagram similar to Fig. 24 but drawn with the particular values obtained for x and y is useful. It gives a picture of the quantities to be determined by the computations in the rest of the reduction thereby aiding in checking the accuracy of the work.

Let the signs of items 52 and 53 be

Item 52	+	+	−	−
Item 53	+	−	+	−
Then the sign of the tangent is	+	−	+	−
The angle is	χ	$180 - \chi$	$180 + \chi$	$-\chi$
In quadrant no.	1	2	3	4
The sign of the cosine is	+	−	−	+
" " sine is	+	+	−	−

Item 60. ρ. The direction angle of the moon's motion is found from

$$\tan \rho = 15\Delta a \cos \delta/(\Delta\delta)'' \qquad (28)$$

item 60 = item 55 + item 56 − item 59

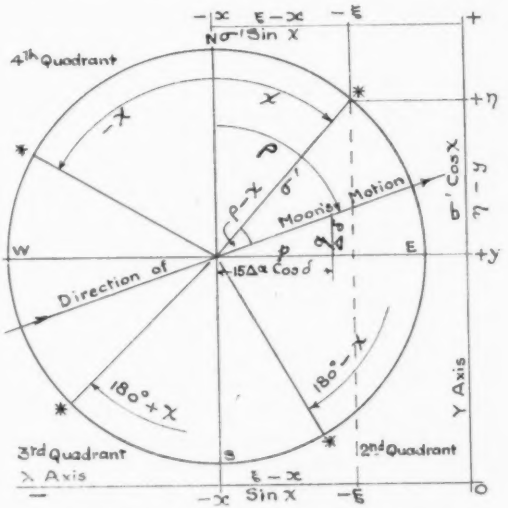

Fig. 24.—Direction angle ρ of moon's motion; position angle x of star and related quantities.

Signs. The signs of $15\Delta a$ (since the moon's right ascension is always increasing) and of cos δ are positive. $\Delta\delta$ will be positive when the moon's declination is positive and increasing or negative and decreasing, and negative in the contrary cases. The sign of tan ρ will therefore depend upon whether the difference of the logarithms is positive or negative.

When tan ρ is positive the moon's motion is to the north of east and the angle is ρ in the first quadrant. When the moon's motion is to the south of east the angle is $180° - \rho$ in the second quadrant and tan ρ is negative.

Item 61, $\chi - \rho$. Note that this difference is now taken in the sense $\rho - \chi$.

Items 61a, $p = \cos(\rho - \chi)$ and 61b, $q = -\sin(\rho - \chi)$. The sign of p is positive for a disappearance and negative for a reappearance. The sign of q is opposite to that of $\sin(\rho - \chi)$. These quantities are used in Dr. Comrie's modification of the Innes method of reduction. A full description of the Comrie method is given in the Occultation Supplement to the Nautical Almanac of 1938, cited above. As it is designed for use where calculating machines are

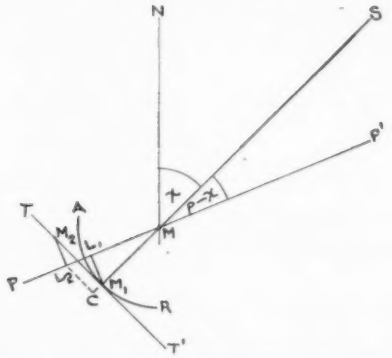

Fig. 25.—Departure of the moon in longitude and latitude from the theoretical position as determined from $\sigma' - \sigma'$. (After Dr. Farnsworth).

available and requires the preparation of special tables for each observational position, the amateur computer, except when reducing only his own observations, probably will find the Innes method more convenient at least for the present.

There remain items 54a and 56a. These represent the rate of change of $\Delta\delta$ and $\Delta\alpha$ consequent upon changing the accepted position of the star should this be necessary in the future.

While the analysis itself is outside the scope of this paper, it is of interest to note how these auxiliary quantities contribute to the

solution of equation 26. What follows is based upon the description in Dr. Farnsworth's paper cited above.

At the instant of the star's disappearance let M, Fig. 25, be the position of the moon's centre on the path PP' lying at an angle NMP', equal to ρ, from the north point of the disc; all as determined from lunar theory. Let S be the known position of the star at this instant. Join MS. Then the angle NMS equal to χ is the theoretical position angle of the star and the angle SMP' the angle $\rho - \chi$.

Now since S is the known position of the star, at the instant of disappearance the moon's centre must be somewhere on an arc AR drawn with S as centre and radius equal to the known radius of the moon, σ meeting MS or MS produced in the point M_1. Then $M_1 - M$ is equal to $\sigma' - \sigma$.

From M_1 draw M_1L_1 perpendicular to PP'. Then ML_1 is the observed difference ΔL in longitude and M_1L_1 the observed difference ΔB in latitude of the moon from its theoretical position. But

$$\Delta L = (\sigma' - \sigma) \cos(\rho - \chi) \text{ and } \Delta B = (\sigma' - \sigma) \sin(\rho - \chi),$$

or
$$\frac{\Delta L}{\sigma' - \sigma} = \cos(\rho - \chi) \text{ and } \frac{\Delta B}{\sigma' - \sigma} = \sin(\rho - \chi),$$

whence since $\cos^2\theta + \sin^2\theta = 1$,

$$\Delta L \cos(\rho - \chi) + \Delta B \sin(\rho - \chi) = \sigma' - \sigma.$$

Since $\sigma' - \sigma$ is small compared with σ no appreciable error will result from replacing the arc AR by its tangent TT', drawn at right angles to SM_1. The centre of the moon may then be regarded as at some point M_2 on TT' near the point M_1. Drawing M_2L_2 perpendicular to PP' and L_2C parallel to TT', $\sigma' - \sigma$ will be represented by MC and

$$\Delta L = ML_2 = (\sigma' - \sigma) \cos(\rho - \chi)$$
$$\Delta B = M_2L_2 = (\sigma - \sigma) \sin(\rho - \chi)$$

whence equation (26) holds as before.

In the preparation of this section my thanks are due especially to Dr. Brouwer and Dr. Alice H. Farnsworth. To Dr. Brouwer for his remarks on the form of the fundamental equation and to Dr. Farnsworth for valuable criticism and suggestions and for permission to use the reduction of 70 Tauri (No. 659) as Figure 16.

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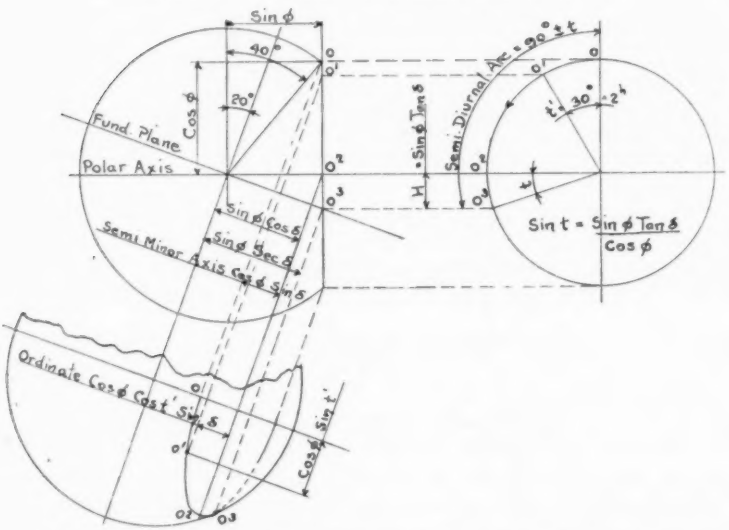
APPENDIX TO "OCCULTATIONS"

Errata

Page 272, l. 22, for $b = r \sin \varphi \cos \delta$ read $r = \cos \varphi \sin \delta$
Page 282, l. 27, $\eta = \sin \varphi \cos \delta' \cos t$ read $n = \cos \varphi \sin \delta' \cos t$
Page 282, l. 34, should be $\eta = 0.723 \times 2822 \times .7934 = .162$

FIGURE ALTERNATIVE TO FIGURES 10 AND 11



This figure shows how each formula is derived, even that for the semi-diurnal arc of the star. The figure is based on the apparent motion of an observer at lat. 40° N as seen from a star whose dec. is 20° N. The earth is assumed as transparent, with the polar axis horizontal, and all that portion north of 40° N lat. lopped off, leaving a truncated sphere. The end view (the circle to the right) shows the observer move from O, when the star would be on the observer's meridian, through O^1 when he would be half-way along the elliptical path on the fundamental plane, through O^2 at the end of the ellipse, and finally at O^3, where he would be lost to sight, or, to the observer, the star would set below the horizon. This movement is projected on the fundamental plane, as shown on the diagram (lower left). All of the formulae required for the problem are shown together with their relations to each other.

(The above were kindly supplied by Mr. Jesse A. Fitzpatrick, New Rochelle, N.Y.)

REVIEW OF PUBLICATIONS

Kepler and the Jesuits, by M. W. Burke-Gaffney, S.J. 138 pages, $5\frac{1}{8}$ x $7\frac{3}{4}$ in., 8 half-tone plates. Milwaukee: The Bruce Publishing Co., 1944. Price, $2.00.

There has been a decided lack in English of an authoritative life of Kepler and this book admirably fills it. Father Burke-Gaffney was born in Ireland in 1896 and graduated there with a degree in Civil Engineering. After some time in the Government service in Dublin he came to Canada in 1920 and was appointed Assistant Bridge Engineer for the Manitoba Government. He has pursued postgraduate studies in astronomy in Canada, Ireland, France and at the Georgetown University, Washington, D.C., where he received the Ph.D. degree. He is now Dean of Engineering at St. Mary's College, Halifax, N.S.

With the training thus indicated Father Burke-Gaffney has been able to examine thoroughly the life-work of Kepler, one of the founders of modern astronomy and yet whose career has been so little understood.

The book contains eleven chapters: (1) Introducing Kepler, (2) The Imperial Mathematician, (3) The New Star, (4) Chronology, (5) The Telescope, (6) Sunspots, (7) Mercury in the Sun, (8) Heliocentric Hypothesis, (9) Comets, (10) Aids to Astronomy, (11) The Last Chapter. Then follow a page of bibliography and a good index.

In each chapter a phase of Kepler's work is described and discussed with a freedom and clarity which render it pleasing to read and easy to understand. Father Burke-Gaffney is very familiar with the political, social and religious condition of countries of Europe in the time of Kepler and his chapters are illuminated with numerous quotations from the writings and correspondence of all the noted in astronomy, philosophy and theology. Indeed one is surprised at the numerous communications which passed between these various men of learning, Jesuit or otherwise; and the author makes them stand out as real live men.

C.A.C.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Strange Phenomenon in the Sky

In our October issue (p. 351) appeared a request for information regarding a puzzling phenomenon observed on August 9, 1944, by Lieut. Tabruh, a member of the staff of No. 100 General Hospital, U.S., in England. Under date November 22, Dr. D. G. Revell, for many years professor of anatomy in the University of Alberta at Edmonton, enclosed a letter dated September 3, 1944, written by his son, Major D. G. Revell, of No. 3 Canadian Casualty Station, R.C.A.M.C., at that time near Rouen in France. Major Revell describes something observed by him which is apparently similar and he makes a suggestion as to the cause. The portion of his letter relating to the phenomenon is given below.

On one of our recent trips while we were awaiting orders in an orchard we watched the planes going over. One can often see their shadows sweep across thin layers of clouds, but this time we saw a new phenomenon which has caused me much thought. Before I could get my camera out it had gone. An apparently thin cloud higher than cumulus levels and below the cirrus, with very indefinite margins—across which passed successive visible waves—or arcs of circularly radiating waves—2 or 3 at a time—and often from different centres, though these were in same general direction—but different distances away (arcs were larger and smaller). I cannot recall whether the compression or rarefaction phase was in the lead. Have concluded that they were sound waves from bombings or guns that we could not hear. If so it is the first visible sound waves I have seen. They travelled much faster than planes, and were definitely not shadows. The cloud (of ice crystals?) evaporated very quickly. We had not seen it form.

The two communications were referred to Mr. W. E. K. Middleton, of the Meteorological Office, who supplies the following note:

There has been some discussion of this phenomenon in recent Meteorological publications, and the opinion seems to be that the bands are due to the very low frequency sound waves caused by large explosions. Such waves have a frequency of only two or three vibrations per second, and would theoretically produce bands far enough apart to be seen, if they were intense enough to alter the size of the cloud particles by evaporation and re-condensation.

Unfortunately I cannot at the moment lay my hand on the reference to the discussion that I have seen published. Of course there is no direct experimental evidence for this, but it does seem a likely explanation for these moving bands.

C. A. C.

Simeiz Observatory

Astronomers of Canada and the United States may well have a feeling of thankfulness that the observatories in this western world have not been in the path of invading armies. In *The Observatory* for October 1944 is an authoritative account of the scandalous treatment given the Simeiz Observatory, which the lovers of liberty and culture should read. The entire brief article is given below.

A telegram received by the Editors from G. A. Shajn, member of the Academy of Sciences of the U.S.S.R., gives a graphic account of the looting of this famous Observatory in the Crimean peninsula. Freed of telegraphic phrases and abbreviations the account reads as follows.

"A week or two before the enemy occupied the southern part of the Crimea, the staff of the Simeiz Observatory was evacuated. The workers took with them the object glasses of the two astrographs and part of the laboratory equipment.

In May 1944, after the Crimea was liberated by the Red Army, the Academy of Sciences sent me to inspect the remains of the observatory. The following facts were established. During September and October 1943, German specialists dismantled all the observatory's instruments and moved them in thirty or more trucks to Simferopol, whence they were dispatched to Germany. The equipment stolen was the 40-in. reflecting telescope, the double astrograph, the new astrograph for zonal observations, a photoheliograph, three stellar spectrographs, a large coelostat, a long-screw measuring machine, a Repsold machine, a microphotometer and two astronomical clocks.

In addition to this, much other laboratory equipment and the whole library collection of over nine thousand negatives, and the equipment of the power station and workshop were all taken away. The wooden parts of three observatory domes were all destroyed, and one of them was used as a stable. The wooden building which housed the spectrohelioscope was destroyed, as were a number of other pavilions.

On January 18, 1944, the main building of the observatory, where a Rumanian army unit was quartered, caught fire. It continued to burn for two days, but the commander of the unit did not call out the fire brigade nor did he take any steps to extinguish the flames. Only the framework of the building remains. Most of the trees in the observatory grounds were felled for firewood.

The two largest observatories in our country, Pulkovo and Simeiz, have been destroyed by the Germans. The Germans may say that Pulkovo was in the battle area and that its destruction was unavoidable; at Simeiz, however, the only shots fired in the vicinity of the observatory were those of firing squads executing civilians."

British astronomers will sympathize with their Russian colleagues in the shameful looting and wanton destruction of this famous observatory. With the arrival of victory as the result of simultaneous pressure from the Red Army and our own forces we look forward to the rise of a new and still greater Simeiz Observatory. C. A. C.

MEETINGS OF THE SOCIETY

February 1, 1944.—The Society met at 8.00 p.m. in the McLennan Laboratory, University of Toronto; Miss R. J. Northcott in the chair. Minutes of the previous meeting and the Annual Business Meeting, held on December 7, 1943, were taken as read.

Squadron Leader J. F. Heard, Ph.D., of the R.C.A.F., addressed the Society on "The History of Navigation." Speaking of the thousands of young members of the air forces whose interest in astronomy had been awakened as a by-product of their instruction in navigation, Dr. Heard said he believed many of them would desire to continue to add to their knowledge of the stars after the war and be sufficiently interested to become members of the Society.

The two basic principles of navigation, either by sea or air, he said, were dead reckoning ("dead" being a corruption of "ded." for deduced), and the use of aids to navigation. To find "D.R." position at sea the navigator must know the starting point, direction (determined by compass), speed (indicated by an instrument known as the log) and elapsed time. When this D.R. position is determined, corrections are made for effects of tide, currents and wind to fix the final "estimated position." In air navigation the problem is essentially the same except that first the "air position"—the location in relation to the ground if *no* wind were blowing—is computed from the speed, direction and elapsed time and then the wind effect is added to determine the D.R. position.

"Dead reckoning is the basis of all navigation—everything else used by the navigator is an aid to navigation, but sometimes these aids are very valuable," Dr. Heard said. In sea navigation the aids include: 1, known landmarks from which the "fix" or position is checked; 2, astronomical aids—determination of latitude from the altitude of Polaris, or from the altitude of the sun or other stars at meridian passage, and determination of longitude from the difference between some standard mean time, usually that of Greenwich, and the local time as determined by observation of the sun at meridian passage (local noon); 3, direction finding by radio, and 4, radar. Allowance has to be made for variation of the compass from true north which varies at different places on the earth, and also for compass deviation caused by the effects of iron in the vessel itself.

Historically, navigation goes far back, Dr. Heard said. The Greeks knew the earth was round and 1,500 years before Columbus' time Eratosthenes had measured its radius with a high degree of accuracy. Columbus' westward voyage to "the East" in 1492, however, contributed greatly to the development of navigation because of its impact upon man's desire to sail farther to sea than ever before.

Columbus had good compasses to aid him, for even by the 13th century the compass had been developed to the point where it could be considered a precision instrument. He knew that in the waters around Europe the compass needle always pointed about five degrees east of true north, but he didn't know

until he discovered the fact toward the end of his voyage that there was such a thing as westerly variation. In Columbus' day the speed of ships had to be judged by the skill of the navigator and here Columbus consistently overestimated by from 10 to 25 per cent. Then he deliberately falsified the ship's record lest his men realize how far they were from land and become alarmed. Now, however, it is known that the "phoney" distances recorded by Columbus were far more like the real distances travelled than those he estimated and kept in his personal log. As there were then no clocks that would run at sea the hourglass was very important to navigators in Columbus' age. Local noon was determined from the sun and time at night by a rule-of-thumb method from the angle of the pole star and Kochab. Columbus had neither a cross-staff nor an astrolabe though both were well known in his day, but he did have a quadrant which, however, he apparently was unable to properly use for his records indicate he could not make an accurate observation of the altitude of Polaris.

The fact that a sailing vessel cannot run into the wind, but has to "tack", must have been quite a problem to navigators, and particularly to Columbus on his lengthy transatlantic voyage, but he apparently had some kind of traverse tables to aid in the difficulties of navigation under such conditions. Columbus was probably the first navigator to notice the diurnal motion of the pole star—in a 3½-degree radius at that time—and later found that his compass showed a variation to the west of true north, thus probably being the first also to discover that compass variation was not constant all over the globe. When he got to Cuba he took a reading of Polaris and set down the altitude as 42°N, adding a note that he knew this could not be correct. The proper altitude for Cuba should have given him a reading of about 21°N. Why he should have made the error and others like it is still a puzzle. Did he not know how to use the quadrant, was his calculation in error, or did he "shoot" the wrong star, possibly beta Cephei which is about the same magnitude as Polaris and at the season he was in Cuba would have given the 42° reading?

For centuries after 1492 the history of navigation revolved pretty much around one burning question—how to determine longitude at sea. Columbus knew where he was going, but he did not know where he was when he got there. Many suggestions were made to enable navigators to find longitude at sea. Galileo proposed that sailors carry tables of the eclipses of Jupiter's satellites from observations of which they could find mean time, but the predictions of the times of these eclipses were not sufficiently accurate for many years, and, of course, Jupiter was not always available. Another proposal was to carry a clock showing some standard mean time to compare with local time obtained from observation of the sun, but such a clock had not been devised which would run properly at sea. A third suggestion was the use of lunar tables showing the moon's position relative to the brighter stars, but here again the tables proved insufficiently accurate.

Nothing was done to solve this problem until early in the 18th century. In 1675 a committee was appointed in England to investigate the matter and on the suggestion of one member, John Flamsteed, King Charles II set up a

national observatory at Greenwich to make a study of star positions and to help devise some method of longitude determination. Flamsteed was made head of the observatory and became Britain's first astronomer royal. In 1713 a prize of £20,000 was offered for a method or device which could determine a ship's position within 30 nautical miles after six weeks out of sight of land. This prize was shared by the widow of the German astronomer Mayer who devised improved lunar tables, and by Thomas Harrison, an Englishman who produced a very remarkable clock which would keep sufficiently accurate time on shipboard—within three seconds error a day. Nathanial Bowditch, the American astronomer and navigator, found he could get quite good results from the method of "lunars" but eventually Harrison's chronometer won out as the best way of finding longitude at sea.

There followed the invention by Hadley of a sextant which enabled much better determination of angles and this instrument is the basis of the modern marine sextant as well as the bubble sextant used in air navigation. Since then improvement in navigation methods has been rapid, some of the factors which have contributed being better knowledge of the variation and deviation of the magnetic compass needle and more accurate charts of the oceans.

Flying introduced some new problems, Dr. Heard said. "All in all astronomical navigation is not as accurate in the air as at sea, and is not likely to become so, but it will continue to be useful as a check on positions determined by other means. Radio methods have proved most useful to the air navigator and will likely do for air navigation what astronomical aids did for marine navigation in the last hundred years or so," he concluded.

After Dr. Heard had answered several questions from the audience, the meeting was adjourned.

February 15, 1944.—The Society met at 8.00 p.m. in the McLennan Laboratory, University of Toronto; Miss R. J. Northcott in the chair.

Four persons were elected to membership in the Society, viz:

Mr. Frank W. Darroch, 337 Annette Street, Toronto.
Mr. V. Malme, 161 Roe Avenue, Toronto.
Mr. Edwin J. Pivnick, 362 Brookdale Avenue, Toronto.
Mr. M. K. Price, 525 Markham Street, Toronto.

Dr. Helen S. Hogg introduced a novel pre-lecture feature in which she took the letters A to E, in turn naming words used in astronomy and physics beginning with the letters, and also star and constellation names and famous astronomers whose names began with the letters. As each group was completed, members whose surnames began with the letter were asked to arise and identify themselves. Hope was expressed by several that the plan, which not only provided a brief summary of astronomical words but also aided members to become known to others, could be continued at future meetings.

Dr. D. W. Best then addressed the Society on "Our Nearest Star—The Sun." To residents of the earth the sun is the grandest and most essential of all heavenly bodies. Not only does its attraction maintain our globe and the other planets in their places, but its rays sustain terrestrial life. The sun is a

star, but so near that astronomers are able to study it in much more detail than other stars. What its study reveals enables astronomers to understand better what the spectroscope tells us about other stars. Sixty-five of the 92 elements known on earth have been identified in the sun, and many lines of known elements have been found in other stars as well. Apparently, then, the whole universe is made of the same kind of "stuff." What we know of the sun may be regarded, with certain exceptions, as true of the other stars in general.

The sun's mean distance is about 93,000,000 miles and this distance is known in astronomy as an astronomical unit. About 16 different methods have been used to determine the solar parallax, the most recent determination being 8.790″. It would require 108 earths in a row to equal the sun's diameter and 1,250,000 earths to equal its volume. The sun's mass is about 333,000 times the earth's, or 744 times the mass of all the planets in the solar system. Its density is one and a half times that of water compared with a density of five and a half for the earth.

Our nearest star rotates on its axis in about 25 1/3 days but the rotation speed varies at the equator and poles, indicating that the sun is not a solid body. The equatorial rotation takes only about 24.7 days. Density, pressure and temperature at the solar surface, about half-way to the centre and at the centre are indicated in the following table:

	Density	Pressure (Atmospheres)	Temperature
At surface	10^{-15}	0.001	6000°C
Half way down	2.5	1000	5×10^6
At centre	85	10^{10}	2×10^7

At the rate of decay of atoms of radioactive elements in the earth, geologists estimate that this planet must be at least 1,500 million years old. The sun must, therefore, be at least something more, possibly 2,000 million years. The fall of solar energy upon the earth is estimated at 4,690,000 horse-power per square mile. How is this enormous output kept up? If the sun were a flaming mass of gas, consuming itself, it would be inadequate to supply this energy. If pure coal, it would burn itself out in 5,000 years. Whence, too, comes the oxygen for combustion? And the sun is *too hot* to *burn*. The surface temperature alone would break the chemical bonds, therefore the solar atmosphere must be composed of pure chemical elements. If we accept the idea of contraction with heat produced by gravitational pressure, it is estimated that the sun might last several million years, but the time is still a thousand times too short to satisfy what is required by the geological evidence of the earth's antiquity.

The hypothesis of radioactive decay and subatomic energy—the carbon-nitrogen cycle—seems able, however, to account for the solar radiation over the required period, and it is believed the sun would thus be able to go on radiating energy at its present rate for at least another 40 million years.

Dr. Best went on to describe recent advances in our knowledge of the sun and how they have opened the door to unbounded progress. Helium, first found in the sun, was later identified with a gas in the earth. Similarly, when certain

lines in the nebulae could not be matched in the laboratory, the substance called nebulium by astrophysicists was later found to be oxygen and nitrogen in an unusual state. For decades observers have been aware of green emission lines in the solar corona and these were attributed to an unknown element "coronium." Twenty-three lines are definitely known to be coronal lines and all but four have new been identified with known elements.

Study of solar prominences would indicate that parts of the sun's atmosphere must be as hot as 25,000°C, while those parts of prominences seen 300,000 miles above the solar surface must be produced by stripped atoms which would require a temperature of 2,000,000°C. According to Menzel, leaks from the deep interior of the sun from which atoms and parts of atoms are forced out into the corona at extremely high temperatures may form the clouds seen high in the solar atmosphere.

Before adjournment, Miss Northcott drew attention to a map of the southern sky for the month, indicating positions of the moon, planets and brighter stars.

February 29, 1944.—The Society met at 8.00 p.m. in the McLennan Laboratory, University of Toronto; Miss R. J. Northcott in the chair.

Mr. Charles A. Crook addressed the Society on "The Sun's Family—Our Planetary Neighbours." Some of the interesting facts he mentioned follow:

Mercury's mean distance from the sun is 35,950,000 miles but the eccentricity of its orbit, 0.206, is so great the sun is 7,400,000 miles out of centre. Thus the planet's distance varies from 28,550,000 to 43,350,000 miles. Mercury's velocity varies from 36 miles per second at perihelion to only 24 at aphelion. Its distance from earth ranges from 50,000,000 miles at most favourable inferior conjunction to 136,000,000 at the remotest superior conjunction; its angular diameter as seen from earth being from 13 down to 5 seconds of arc.

Mercury always turns the same face toward the sun. Thus part of the surface has perpetual day and part perpetual night. On account of the great eccentricity, however, only about three-eighths of the area falls within each of these regions. In the remaining quarter of the surface the sun alternately rises and sets. The temperature of the part always bathed in sunlight is about 750°F, considerably higher than the heat at which lead melts. The other side must be intensely cold.

Could there be life on Mercury? Sir James Jeans says: "The planet gravitationally is too feeble to retain much of an atmosphere and its surface, insofar as this can be tested, appears to consist mainly of volcanic ash like the moon and Mars." Mercury, therefore, does not appear promising as an abode of life. As the velocity of escape of gases is 2.4 miles per second, the atmosphere, if any, must be extremely rare. The albedo, 0.07, would indicate that light is reflected from a solid surface, rather than from an atmosphere.

Venus, the earth's twin sister, is the brightest and most conspicuous of any planet or star in our skies. It can be seen easily with the naked eye in day time when at its brightest. Its distance from earth ranges from 26,000,000 to 160,000,000 miles and its apparent diameter varies from 64″ to only 10″. The axial rotation is still in doubt but it seems reasonably certain that it does not

always turn the same face toward the sun. Recent observations indicate a period of about 30 days. The temperature of the sunlit surface has been measured at about 60°C while that of the dark side is about —20°C.

As Venus is blanketed in cloud we can only guess about its surface but its atmosphere has been studied. There appears to be little oxygen but an abundance of carbon dioxide. Nitrogen is probably present, but in smaller amounts than on earth. It would appear that Venus is a world where life has not yet developed, a world where conditions are not greatly different from those that existed on our earth many hundreds of millions of years ago. As conditions become more suitable for life on Venus they will become less favourable for its continued existence on our planet.

To an observer on Venus the earth when nearest would be a very brilliant object; about six times as bright as Venus at brightest appears to us. When the two planets are near each other almost the whole of the illuminated side of the earth is visible from Venus while very little of that of Venus is visible from the earth. From Venus, our moon would appear as bright as we see Jupiter and it would oscillate back and forth within half a degree of the earth, the pair resembling a double planet rather than a planet and satellite.

Mars' mean distance from the sun is 141,500,000 miles but as its eccentricity is considerable, 0.093, the distance varies more than 26,000,000 miles. Mars' average distance from earth at opposition is 48,600,000 miles, but when opposition occurs near the planet's perihelion, always about the end of August, this may be reduced to 34,600,000 miles. The next such occasion is in 1956. The average distance at conjunction is 234,000,000 miles. The stellar magnitude varies from 1.6 to —2.8, the planet being 55 times as bright at favourable oppositions as at the average conjunction.

Some of Mars' surface markings are subject to seasonal changes which make their study of unusual interest. About three-eighths of the surface is a bluish-grey or greenish shade. The reddish areas, which show little or no change with the seasons, are considered to be rocks that have been completely oxidized. This is indirect evidence of oxygen although attempts to detect the gas in Mars' atmosphere have been unsuccessful. It appears probable that weathering of the rocks, followed by their oxidation, has resulted in almost complete depletion of oxygen from the atmosphere. There may be some oxygen left, however, which might account for the seasonal changes if these are regarded as due to some form of vegetation. The small amount of oxygen would seem to make existence of animal life, particularly in its higher forms, improbable; but, on the other hand, life could exist if constituted differently to that on the earth.

But Mars, though perhaps in past ages the abode of life, is now a dying world which has lost most of its atmosphere and most of its moisture—a planet of spent life. Such vegetation as now continues to maintain a precarious existence must be doomed to extinction in a time which geologically is not remote.

Jupiter is the giant of the sun's family, larger than all the other planets combined. Most startling of all its surface features is the great Red Spot,

identified on drawings made as long ago as 1831. It does not rotate uniformly with the planet but drifts about, so is unquestionably a floating disturbance. Other such wandering markings have been observed, indicating that the Jovian atmosphere is deep and complex. The great clouds seen around Jupiter are composed of ammonia and methane, both very rich in hydrogen. As the surface temperature is about —216°F the ammonia must be frozen but the methane is gaseous. The clouds, therefore, likely consist of small ammonia crystals suspended in the atmosphere. It is certainly not feasible that life could exist on Jupiter. Transferred there we would be simultaneously frozen, asphyxiated, poisoned and pressed to death by the terrific atmospheric pressure.

Jupiter's four largest satellites are excellent reflectors of light and their surfaces must be very different from that of our moon, perhaps covered with frozen gases. Ganymede, only 0.6 as dense as water, may consist of some substance like the outer layers of Jupiter itself.

Saturn, most beautiful of the planets because of its ring system, makes a unique and striking object when seen in the telescope. How did these rings, consisting of numberless tiny moons circulating around the planet, get there? There seems to be little doubt but that they are fragments of a former satellite which approached the planet too closely and was disrupted by gravitational pull.

Saturn, like Jupiter, appears to have a dense atmosphere, but with more methane and less ammonia, and probably a good deal of hydrogen in the lower layers. Since the temperature is —273°F we may conclude that more of the ammonia has frozen out and the reflected sunlight penetrates a thicker layer of methane. Recently Dr. Kuiper of the McDonald Observatory in Texas obtained a spectrogram of the satellite Titan which indicated an atmosphere of methane and possibly ammonia. This is the only moon in the solar system which is known to have an observable atmosphere.

Uranus appears distinctly green in the telescope, thus indicating a heavy atmosphere of methane. Because of the temperature of —300°F the ammonia crystals may have settled out of the gaseous strata. . . . Neptune with a temperature of —330°F, apparently has even less ammonia than Uranus but a very dense atmosphere of methane. . . . Pluto, the latest "addition" to the sun's family, was discovered in 1930. It is 3,666,000,000 miles out from the sun and takes 247¾ years to revolve around it.

The Chairman referred to the recent discovery of a dark object, apparently larger than Jupiter, which had been found because of its gravitational pull on the star 61 Cygni, and which was the cause of speculation as to whether it was a dark star or possibly the first planet to be discovered outside our own solar system. Several members took part in a brief discussion on the possibility of planetary systems being attached to other stars than the sun.

Also, while outlining the positions of the moon and planets, Miss Northcott mentioned that occasionally February passes without a full moon, the month being shorter than the lunation period. Such years were 1915, 1934, 1961, 1999 and 2018 when one full moon occurs very late in January and the next early in March.

FREDERIC L. TROYER, *Recorder.*

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